Power Quality Improvement Using Matrix Converter Based UPQC

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Abstract– This paper proposes a matrix converter based unified power quality conditioner (MC–UPQC) for mitigating power quality problems. This proposed system is a combination of unified power quality conditioner and matrix converter. The UPQC is a combination of back-to-back connected series and shunt active filters through a dc-link. Voltage disturbances and harmonics are compensated by series active filter. Current harmonics are mitigated by shunt active filter. The matrix converter regulates the frequency. the performance of (MC–UPQC) is compared with fuzzy controller against the PI controller. The proposed system is modeled and verified using MATLAB/Simulink

I. INTRODUCTION

The interconnection of many loads especially the increased use of non linear loads in distribution system can cause several kinds of disturbances. Those disturbances are voltage sag, voltage swell, supply frequency variations, voltage harmonics and current harmonics. The economic development of a power system mainly depends on the quality and reliability of power. The above mentioned disturbances can cause the degradation of quality of power [1]. As the quality of power reduces the electrical equipments are not work properly and they fail to operate. In order to work the electrical devices properly we have to improve the quality of power.

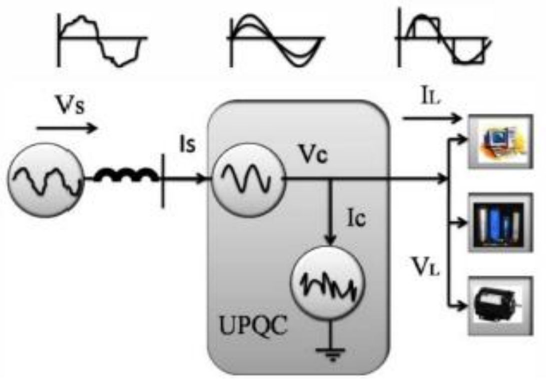


Fig 1: basic configuration of UPQC

The custom power devices enhance the quality and reliability of power to the customers. With the custom power devices a customer receives a pre specified quality of power. The unified power quality conditioner (UPQC) is one of the advanced custom power device in the area of power quality improvement. The basic configuration of UPQC is shown in fig 1.The UPQC provides instantaneous sampling of source voltage and load current by using series inverter and shunt inverter respectively.

As mentioned the above disturbances [2] [3] [4] are compensated by using UPQC except the supply frequency variations. In UPQC there is no device particularly for the frequency regulation. So the proposed system is a combination of a matrix converter and the UPQC for compensating all power quality problems.

II. NECESSITY OF FREQUENCY QUALITY

Frequency is an important parameter in the interconnected power system. It is common to all customers in one synchronous area. The amount by which a frequency differs from a nominal value is known as frequency deviation.

The absolute frequency deviation

$$\Delta f = f - f_s$$

Where

f_s= standard frequency (50 or 60 Hz)

f=actual frequency

The relative frequency deviation

$$\Delta f = \frac{f - f_s}{f_s} \times 100$$

The supply frequency is a continuously changing variable that is determined by the real time balance between the load demand and total generation.

According to the standard En 50160 the standard frequency of supply voltage is 50Hz. The allowable limits of frequency are set for a percentage of observation time in any period of one week.

The limits are

50Hz ± 1% for 95% of the time in one week

50Hz + 4% to –6% for 100% of the time in one week

The choice of frequency in an AC system is influenced by several factors such as lighting, motors, transformers etc.

A. Effect of frequency variations on lighting

If an incandescent lamp is operated on a low-frequency current, the filament cools on each half-cycle of the alternating current, leading to perceptible change in brightness and flicker of the lamps; the effect is more pronounced with arc lamps.

B. Effect of frequency variations on rotating machines

The synchronous speed of the motor varies linearly with the electrical frequency and inversely with the number of poles according to the below equation.

$$N = \frac{120f}{P}$$

For a motor the number of poles is fixed. Any variation in the frequency will affect the speed of the motor.

Torque in an induction motor is proportional to the ratio of the voltage to frequency (V/f Ratio). Even when the change in the frequency, if the applied voltage too is changed in the same proportion, that is if the V/f ratio is kept constant, then torque would remain constant and it wouldn't change.

Motor torque=flux density*I

Flux density=K*(V/Hz)

Where

K=motor constant

V=voltage

Hz=frequency

Motor torque= $\left(K * \frac{V}{Hz}\right) * I$

C. Effect of frequency variations on transformers.

The RMS value of induced emf in primary winding is

$$E_1 = 4.44fN_1\emptyset_{max}$$

The RMS value of induced emf in secondary winding is

$$E_2 = 4.44fN_2\emptyset_{max}$$

Where

N_1, N_2=number of turns in primary and secondary winding

$\emptyset_{max}$=maximum flux in webers

The maximum magnetic flux in the core is proportional to the volts per turn and inversely to the frequency. If we increase the frequency the maximum flux in the core falls, so we have less copper losses. But also the iron losses increase (eddy currents and hysteresis loss). If we decrease the frequency, the maximum flux increases, We have less iron loss, but we increase copper losses. A small decrease in frequency from nominal will probably reduce the KVA rating.

III. PROPOSED SYSTEM

A. MC–UPQC structure

The proposed configuration of the MC–UPQC is shown in fig 2. It is the combination of UPQC and matrix converter. This proposed system enables the UPQC for voltage, current disturbances and a matrix converter for frequency regulation.

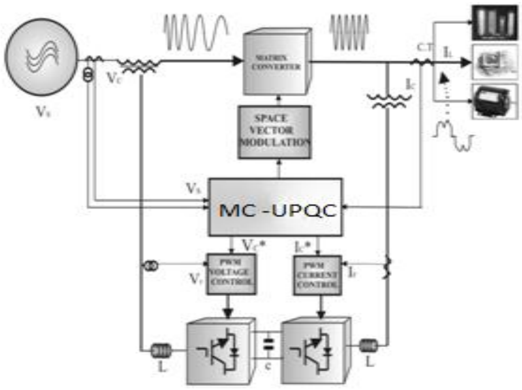


Fig 2: proposed configuration of MC–UPQC

The control strategies of this proposed system will be explained in coming sections. The proposed system should satisfy the following requirements. Maintain the load voltage value near to the supply voltage. A very low harmonic content in the input current. Reactive power control and the supply frequency should be maintained within the limits.

This proposed system consists of series active filter, shunt active filter and a matrix converter. Here the matrix converter is an AC-AC converter. This can regulate the frequency instead of a cyclo-converter. Compared to conventional AC-AC converter the matrix converter has the following advantages. In matrix converter there is no dc storage element, which reduces the size and weight of the converter. This can eliminates the limited life of electrolyte capacitors. For the compensation of voltage disturbances and voltage harmonics the series active filter is used. The shunt active filter eliminates the current harmonics and also compensates the reactive power. In addition to this it supplies power to the DC-link. The control equation of parallel active filter is

$$I_{pf} = G.I_L \rightarrow |G(j\omega)| = \begin{cases} 0, \omega = \omega 1 \\ 1, \omega = \omega_h \end{cases}$$

Where

I_{pf} = input current of shunt active filter for compensation
G = control function
I_L = load current
ω = fundamental frequency

The parallel converter uses a hysteresis band for current control. I_{pf} is obtained from the load voltage and load current.

The series active filter mitigates the supply harmonics, voltage disturbances like voltage sag, voltage swell and the load harmonics entered into the parallel filter. The control equation of the series converter is

$U_{sf} = K.G.I_{sh} + U_{comp}$
Where

U_{sf} = voltage of series filter
K = regulator gain
I_{sh} = harmonic current of supply
U_{comp} = compensation voltage

B. control scheme of frequency changer

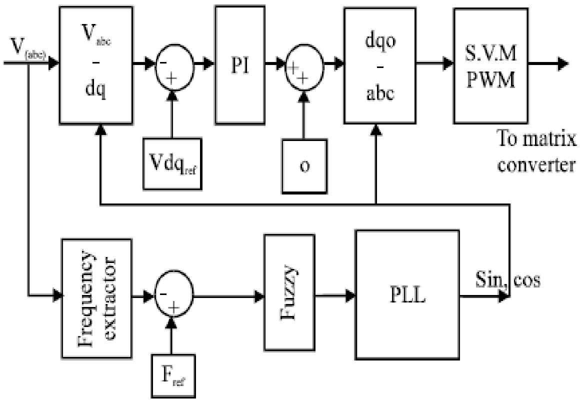


Fig 3.control scheme of frequency changer

The matrix converter works as a frequency changer. It consists of 9 bi-directional switches that allow any output phase to be connected to any input phase. The switches of matrix converter are controlled by space vector modulation [5]. The switching function S_{ij}, is defined as the representation of the switch connecting input line i to the output line j. when the switch is ON the switching function S_{ij}=1 and when the switch is OFF S_{ij}=0. The control system of matrix converter is shown in fig 3. For the operation of matrix converter one and only one switch in each output phase must be conducting. The output frequency is regulated by using modulation reference voltage.

The frequency of the supply voltage is sensed by the frequency extractor. This supply frequency is then compared with the reference value of frequency and the error value extracted. The error and change in error are the two inputs given to fuzzy logic controller (FLC). Then FLC provides the compensated value and this value is fed to the PLL. When the frequency changes from the power quality limits, then the matrix converter changes the required frequency through FLC.

FLC consists of three stages: fuzzification, inference engine and defuzzification.

Fuzzification: Fuzzification is the process of changing a real scalar value into a fuzzy value. This is achieved with the different types of membership functions using linguistic variables.

Inference engine: Fuzzy inference is the actual process of mapping from a given input to an output using fuzzy logic. It uses a collection of fuzzy membership functions and rules. In this system the rules are defined and stored. A rule base contains a number of fuzzy IF–THEN rules.

Defuzzification: It is the process of converting the fuzzy values back into the real scalar values.

As the fuzzy controller is a multi input multi output system, here the error and deviation in error are the two inputs to the FLC. Then it is required to choose the membership function. Here five membership functions are taken for each input. Those are **NB** (negative big), **NS** (negative small), **Z** (zero), **PS** (positive small), **PB**(positive big). With these five membership functions we can form twenty five rules as shown in table 1.

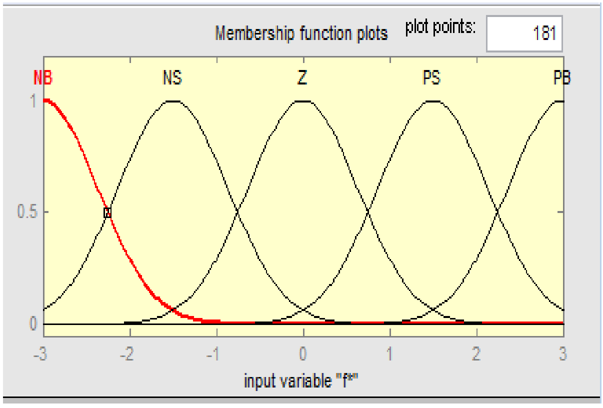
e **ė**	**NB**	**NS**	**Z**	**PS**	**PB**
NB	**NB**	**NB**	**NB**	**NS**	**Z**
NS	**NB**	**NS**	**NS**	**Z**	**PS**
Z	**NB**	**NS**	**Z**	**PS**	**PB**
PS	**NS**	**Z**	**PS**	**PS**	**PB**
PB	**Z**	**NS**	**PB**	**PB**	**PB**

Table 1: fuzzy rules

The various membership functions used in fuzzy are triangle, trapezoidal, Gaussian and sigmoid. In the present work the membership function used is Gaussian. The Gaussian membership function is:

$$f(X, \sigma, C) = \frac{e^{-(x-c)2}}{2\sigma^2}$$

Where
C=center
σ = width of the fuzzy set



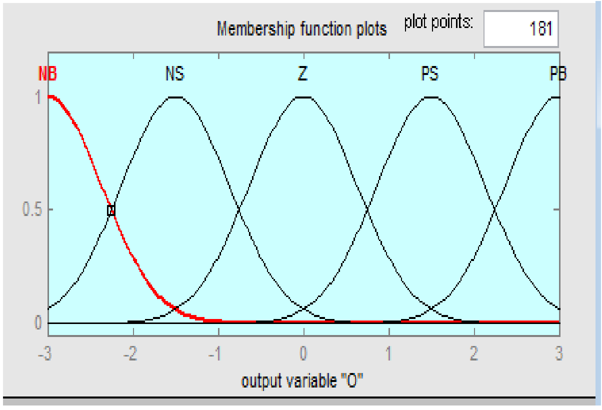


Fig 4. Input and output membership functions of FLC

In the present system the inference engine used is mamdani. The input and output memberships used in this work is shown in fig 4. Here all the membership functions are uniformly distributed in the range [-3,3]. In mamdani inference system the rules are simulated and gives the output in fuzzy. Then defuzzification is done inorder to convert the fuzzy values into the real scalar values using centroid method.

C. Control strategy for the MC–UPQC shunt inverter:

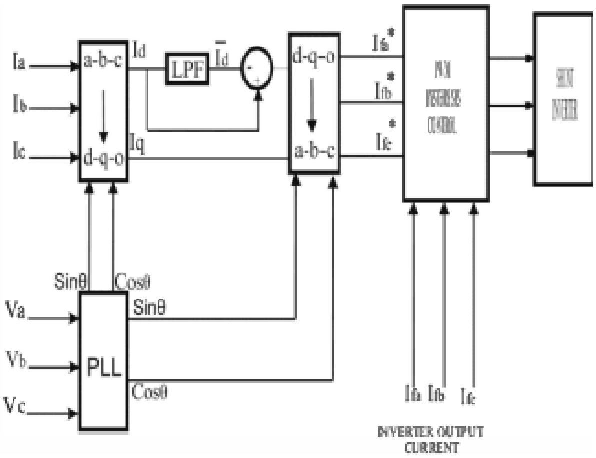


Fig 5. Control strategy of MC–UPQC shunt inverter

The controlling diagram of shunt inverter of MC–UPQC is shown in fig 5. The control block diagram uses the synchronous reference (SRF) theory. Here load currents I_a, I_b and I_c are given. These sensed load currents are transferred into dqo rotating reference frame using parks transformation. The required sin, cos functions are obtained through load voltage using PLL. Here the load currents are divided into dc and ac components.

$$I_{ld} = \bar{I}_{ld} + \tilde{I}_{ld}$$

$$I_{lq} = \bar{I}_{lq} + \tilde{I}_{lq}$$

Here I_{ld}, I_{lq} are the real and reactive components of the load current. With low pass filter the ac and dc components are extracted.

The control strategy generates the reference currents for the compensation of current harmonics. The reference currents are

$$I_{fd}^{*} = \tilde{I}_{ld}$$

$$I_{fq}^{*} = \bar{I}_{lq}$$

With the inverse peak transformation the reference currents are transformed back to the (a_b_c) frame. Then the resulted reference current and the shunt inverter output current are fed to the hysteresis band controller. Now the hysteresis controller generates the required controlling pulses to the shunt inverter gates. Then the required compensation current is generated.

D .control strategy of MC–UPQC series inverter:

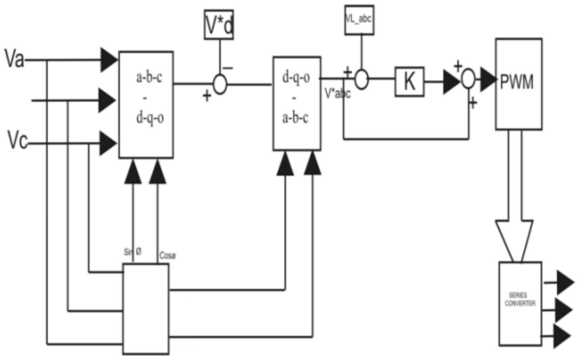


Fig 6. Control strategy MC–UPQC series inverter

The controlling block diagram of series inverter of MC–UPQC using SRF theory is shown in fig 6. Here the series inverter voltage is sensed and transformed into dqo rotating reference frame using

$$V_{t\_dqo} = T_{abc}^{dqo} V_{t\_dqo}$$

This voltage is compared with load voltage and the result is considered as the compensated voltage. In the dqo rotating frame the reference voltage is

$$v_{sf\_dqo}^{ref} = v_{t\_dqo} - v_{l\_dqo}$$

This reference voltage is then transformed back into the (a_b_c) frame. This reference value and the load voltage are fed to the PWM generator. Then the required gate pulses are generated for the series inverter. Then the series inverter generates the required voltage.

IV. SIMULATION RESULTS

The proposed system, simulation results is simulated by MATLAB software.

The simulation of matrix converter without UPQC is shown in fig 7. Here the rms line voltage is 440v. The supply current is 200A. The simulation time start from 0.02 to 0.085. In fig 7 the simulation time consider from 0.02 to 0.08. Fig 7(a) shows the supply voltage waveform. It is free from harmonics. Fig 7(b) shows the supply current waveform matrix converter. It is non sinusoidal and contain harmonics. Fig 7(c) shows the load voltage waveform. Fig 7(d) shows the load current wave form. Here the load is resistive.

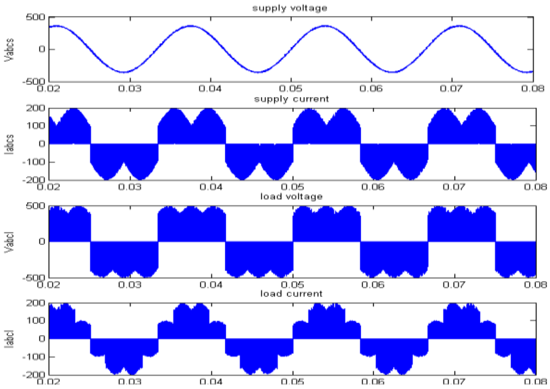


fig 7: (a) supply voltage (b) supply current (c) load voltage (d) load current without UPQC

Fig 8(a) shows the matrix converter output voltage. Simulation results show that it contains harmonics. Fig 8(b) shows the load current waveform. The simulation results confirm that the load current is sinusoidal and harmonic free with UPQC.

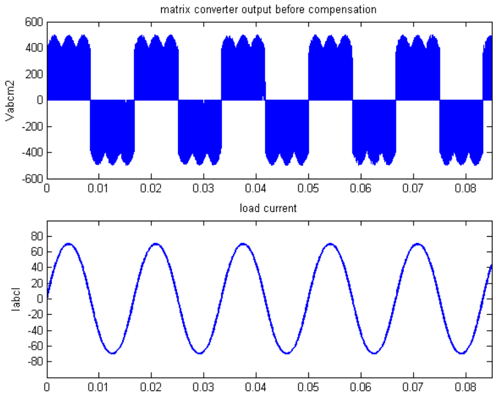


Fig 8: (a)matrix converter output voltage without compensation (b) load current with UPQC

Fig 9 and fig 10 shows the total harmonic distortion (THD). Fig 9(a) and 10(a) shows THD in matrix converter input voltage. There is no harmonic present. Fig 9(b) and 10(b) shows THD in matrix converter output current. Fig 9(b) contains 60% of harmonic distortions but in fig 9(b) it is reduced to 35.6% with fuzzy controller. Fig 9(c) and 10(c) shows the THD in load current. In fig 9(c) THD is reduced to 1.4% with the PI controller based compensation but with fuzzy it is reduced to 0.84% as shown in fig 10(c).

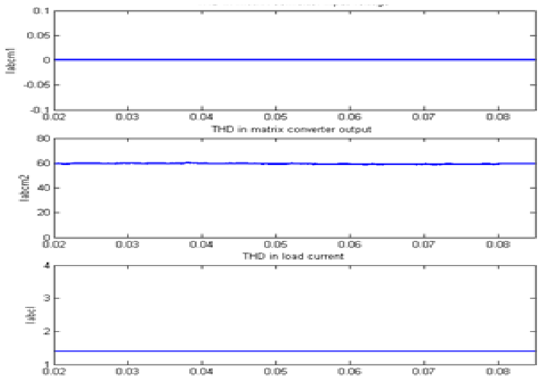
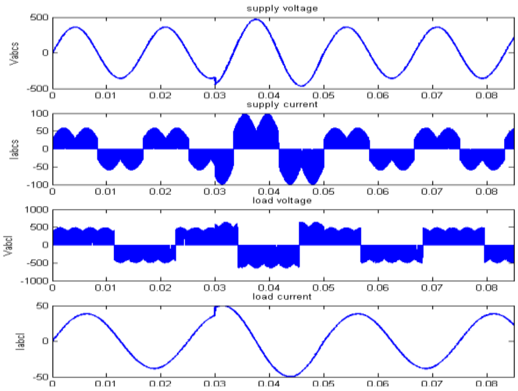


Fig 9: (a) THD in matrix converter input voltage (b) THD in matrix converter output current (c) THD in load current with PI controller based compensation.



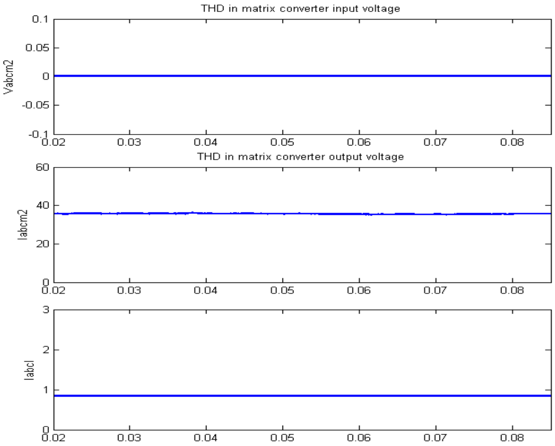


Fig 10: (a) THD in matrix converter input voltage (b) THD in matrix converter output current (c) THD in load current with fuzzy controller based compensation

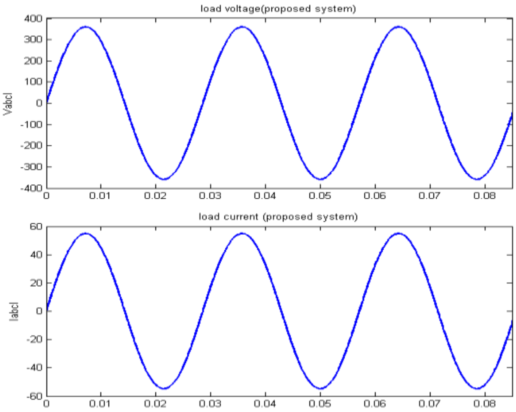


Fig 11: (a) voltage swell in supply voltage, (b) supply current before compensation, (c) load voltage, (d) load current without UPQC

Fig 11 shows when the system is affected by voltage swell. The swell presented at 0.03sec to 0.05sec. Fig 11(a) shows the swell in supply voltage and fig 11(b) in supply current. Fig 11(c) and 11(d) shows the supply voltage variations directly affect the load voltage and current.

Fig 12(a) shows the load voltage and fig 12(b) shows the load current simulation waveforms with proposed system. It is clear that the proposed system eliminates the swell problem.

Fig 12: (a) load voltage and (b) load current with proposed compensation

Fig 13 shows the system response when the supply frequency falls below the power quality limit. In fig 13(a) the supply frequency reduced from 60Hz to 55Hz. With the proposed system the frequency is regulated to 60Hz at the load is shown in fig 13(b).

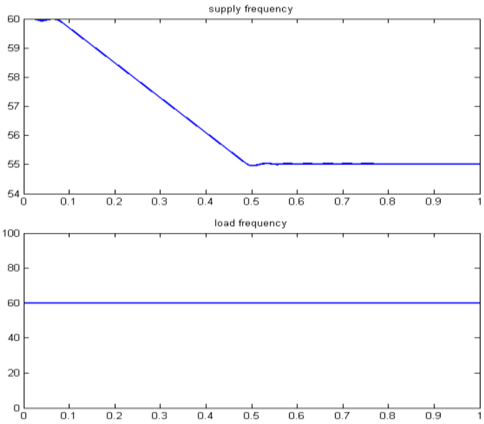


Fig 13: (a) supply frequency fall below the power quality limit (b) load voltage frequency with proposed compensation

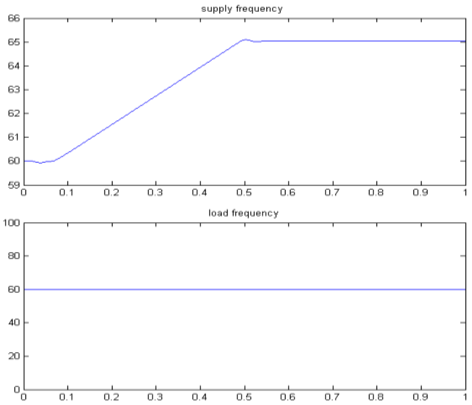


Fig 14: (a) supply frequency rise above power quality limit (b) load voltage frequency with proposed compesation

Fig 14 shows system response when the supply frequency rise above the power quality limit. In fig 14(a) the frequency is raise from 60Hz to 65Hz. With the proposed system frequency is regulated to 60Hz at the load is shown in fig 14(b).

V. CONCLUSION

A model of MC–UPQC has been presented in this paper. The operation and control of MC-UPQC illustrated. It is connected in between source and load. When an unbalanced load is supplied through MC–UPQC it will mitigate voltage, current harmonics, and voltage disturbances. It will also regulate supply frequency variations. The simulation results confirmed that the proposed system has the capability to compensate all power quality related problems.

REFERENCES

[1] Masoud Aliakbar Golkar "Electric Power Quality: Types and Measurements" l EEE International Conference on Electric Utility pp 317-322vo1 2 April 2004.

[2] Aredes, M. Fernandes, R.M. Electr. Eng. Program, I "A unified power quality conditioner with voltage SAG/SWELL compensation capability" Power Electronics Conference, brazil, vol4, pp218 – 224 2009.

[3] Saul Lopez Arevalo, MSc “Matrix Converter for Frequency Changing Power Supply Applications”, January 2008.

[4] T. Benslimane, K. A1iouane, and B. Chetate "Voltage and Current Disturbances Elimination with Reactive Power Compensation Using Unified Power Quality Conditioner" International Symposium on Power Electronics, Electrical Drives, Automation and Motion.voI3,pp24-28,nov 2006.

[5] Nguyen Khanh Tu Tam, Nguyen Van Nho and Huynh Thai Hoang, “Indirect Space Vector Modulated Three Phase ac-ac Matrix Converter under Abnormal Input Conditions”, IEEE PEDS 2011, Singapore, 5 - 8 December 2011.

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